ANNUAL PROGRESS REPORT

Paleolimnology of Selected Lakes in the Southwest Alaska Network: Understanding Past Trends of Salmon Abundance and Lake Productivity

Bruce P. Finney

Institute of Marine Science
School of Fisheries and Ocean Science
University of Alaska Fairbanks
Fairbanks, AK 99775

January 2005

National Park Service
Southwest Alaska Network
Inventory and Monitoring Program

Interagency Agreement Number F9855030030

Funding Source:
Inventory and Monitoring Program, National Park Service

File Name: Finney_2005_SWAKPaleo.doc

Recommended Citation:
Finney, Bruce P., 2005. Paleolimnology of Selected Lakes in the Southwest Alaska Network: Understanding Past Trends of Salmon Abundance and Lake Productivity. USDI National Park Service, Anchorage, AK. 39 pg.

Topics:
Research; Subtopics: Biological, Geological, Water, Climate

Theme Keywords:
Paleolimnology, Salmon abundance, Lake productivity, Paleoenvironmental history, Climate change

Placename Keywords:
Alaska, Southwest Alaska Network, Alagnak National Park Unit, Aniakchak National Park Unit, Katmai National Park Unit, Kenai Fjords National Park Unit, Lake Clark National Park Unit

Initial Distribution:
Southwest Alaska Network, Inventory and Monitoring Program, National Park Service

Abstract

Paleolimnological techniques on selected lakes in the Southwest Alaska Network of the National Park Service are utilized in this project to better understand processes and long-term trends in their biota and environments, with a focus on sockeye salmon (*Oncorhynchus nerka*) lakes. Past changes in sockeye salmon abundance will be determined using stable nitrogen isotope analysis of sockeye nursery lake sediment cores. Data will be developed to reconstruct lake productivity and sockeye salmon abundance over the past 500 to 10,000 years. This data will help define the natural variability of sockeye salmon in these systems, and its relationship to past changes in climate, landscape processes, ocean condition and commercial fishing. In this second annual report of the three-year project, field and laboratory results from the second year (2004) are highlighted. Cores from 9 Lakes in Katmai, Alagnak, and Lake Clark National Park Units were recovered, and preliminary sedimentary analysis and dating has begun. Analysis continued on the cores recovered in 2003. The longest core from Nonvianuk Lake appears to extend to the last deglacial period (> 10,000 yr BP), based on the presence of glacial sediments and a non-alder pollen assemblage at depth in the core. The sedimentary $\delta^{15}N$ is relatively high, suggesting variable contributions of salmon-derived nutrients over time. Sediment cores from JoJo Lake, presently a non-anadromous system, show evidence for a connection to the Naknek drainage in the past. The core has intervals of relatively high $\delta^{15}N$, suggesting the presence of anadromous salmon in the past. The $\delta^{15}N$ variability in Naknek Lake over the past 800 years is likely related to fluctuations in salmon abundance, with the lowest values observed over the past 50 years. The Brooks Lake $\delta^{15}N$ values are relatively low, but the variability over the past ~4000 years may be controlled by changes in salmon abundance. Radiocarbon dates from the Meshik Lake cores suggest the lake formed about 1700 years ago. The relatively low $\delta^{15}N$ values suggest minor contributions from salmon. Cores from Surprise Lake span the last ~450 years, and show a trend of increasing $\delta^{15}N$ over this time, which could be due to salmon colonization and run development following the major eruptive event at ca. 500 yr BP. Overall, the sediments recovered from these lakes have characteristics that will allow for reconstructing aspects of limnological and environmental history.

Executive Summary

This project is using paleolimnological techniques on selected lakes in the Southwest Alaska Network of the National Park Service to better understand processes and long-term trends in their biota and environments. Long-term data will be developed to reconstruct lake productivity and sockeye salmon abundance over the past 500 to 10,000 years. Past changes in sockeye salmon abundance will be determined from new techniques utilizing stable nitrogen isotope analysis of sockeye nursery lake sediment cores. This data will help address questions relevant to sustainable management of these systems by defining the natural variability of sockeye salmon, and its relationship to past changes in climate, landscape processes, ocean condition and commercial fishing. Studies of non-salmon systems will help distinguish how these same factors influence freshwater systems in the absence of salmon. The long-term perspective developed through this project will provide baseline data on these systems, which will help determine how humans have influenced these lake ecosystems, through both local and global activities. Finally, this work will provide insight into how future environmental changes may influence freshwater characteristics and salmon productivity in this region, and provide a better understanding of the significance of trends observed in the Network's future monitoring program.

In 2004, cores from nine additional lakes were retrieved and analysis continued on the cores collected from four lakes in 2003. The cores from Nonvianuk lake appear to extend to the last deglacial period (> 10,000 yr BP), and sedimentary $\delta^{15}N$ is relatively high, suggesting variable contributions of salmon-derived nutrients over time. Sediment cores from JoJo Lake, presently a non-anadromous system, show evidence for a connection to the Naknek drainage in the past. The $\delta^{15}N$ variability in Naknek Lake over the past 800 years is likely related to fluctuations in salmon abundance, with the lowest values observed over the past 50 years. The Brooks Lake $\delta^{15}N$ values are relatively low, but the variability over the past ~4000 years may be controlled by changes in salmon abundance. The Meshik Lake cores suggest the lake formed about 1700 years ago. The relatively low $\delta^{15}N$ values suggest minor contributions from salmon. Cores from Surprise Lake span the last ~450 years, and show a trend of increasing $\delta^{15}N$ over this time, which could be due to salmon colonization and run development following the major eruptive event at ca. 500 yr BP. Overall, the sediments recovered from these lakes have characteristics that will allow for reconstructing aspects of limnological and environmental history.

Introduction

This project is a detailed paleoecological and paleoenvironmental study on selected lakes in the Southwest Alaska Network of the National Park Service. The research will help to better understand processes and long-term trends in the biota and physical/chemical limnology of these freshwater systems. Paleodata can reveal how climatic, oceanographic and landscape processes interact with lakes. In addition, this long-term perspective will provide baseline data on these systems, which will help determine how humans have influenced lake ecosystems, through both local and global activities. Fieldwork for this project began in July of 2003, and cores from Brooks, Naknek, Surprise and Meshik Lakes were obtained. In June 2004, cores were obtained from Nonvianuk, JoJo, Devil's Cove, Hammersly, Murray, Klosterman and Pringle Lakes in the Katmai and Alagnak National Park Units. In September 2004, Kontrashibuna Lake was cored in the Lake Clark National Park Unit. In addition, through collaboration with the U.S.G.S. and Northern Arizona University, sediment samples were obtained from Cresent Lake in the Lake Clark National Park Unit, cored in 2004. Results from these cores obtained in 2004 are described here.

Recent studies at the Institute of Marine Science, University of Alaska Fairbanks, have led to the development of a method to reconstruct long-term changes in salmon abundance from sediment core analysis. This method is based on the observation that salmon strongly impact freshwater environments via input of significant quantities of marine-derived nutrients released from carcasses after spawning. This input, which can be quantified through analysis of $\delta^{15}N$, will vary depending on escapement. Therefore, downcore changes in the abundance of $\delta^{15}N$ will reflect changes in the number of returning adult salmon. Rationale, evaluation and further details regarding the sedimentary nitrogen isotope technique are summarized in Finney et al. (2000).

The sediment ^{15}N method is well suited for sockeye systems because their life history generally requires a lake for habitat. Importantly, lake sediments are often ideal for high-resolution paleoenvironmental studies due to relatively rapid, continuous sedimentation, and minor bioturbation. Recent results on Alaskan sockeye nursery lake sediments show that this technique is applicable to many productive sockeye systems (Finney et al., 2000). Studies combining ^{15}N analysis with standard paleolimnological techniques provide an opportunity to address questions such as:

- What is the natural variability of sockeye salmon in these systems?
- How have past changes in factors such as climate change, ocean conditions, and commercial fishing effected salmon runs?
- How important are salmon-derived nutrients in regulating freshwater productivity?
- Are current escapement goals compatible with the long-term paleoecological perspective?
- Do different lake types respond differently to the same external forcing?
- How might future environmental change influence salmon productivity in these systems?
- How might future environmental change influence freshwater characteristics?

Very little is known about the aquatic ecosystems and prehistoric salmon production in the Southwest Alaska Network. Obtaining a better understanding of these lakes is important from both ecologic and economic viewpoints. This work will provide baseline information and a long-term perspective on these lake ecosystems. Cores will be retrieved from a suite of different lakes in Alagnak, Aniakchak, Katmai, Kenai Fjords and Lake Clark National Park units. Lake characteristics will include glacial, clearwater, anadromous and barriered systems.

The main objectives of this study are:

1. To reconstruct past changes in salmon abundance using the methods developed by Finney et al. (2000), for sockeye salmon systems and systems that may have had salmon in the past. The time frame of such reconstruction's ranges from detailed decadal-scale variability over the last 500 years, to long-term changes since the end of the last ice age (ca. 12,000 years BP).
2. To determine past changes in lake primary productivity and nutrient status, for both salmonid and barriered systems. The time frame will match that in objective 1.
3. To compare these reconstructions to records of past environmental change to determine how factors such as climate change, volcanic eruptions, geomorphologic change and human impacts influence these freshwater systems.
4. To describe long-term trends in sockeye abundance, assess recent levels from a long-term perspective, and compare trends to those determined for other Alaskan systems. Time-series analysis will be used where applicable.
5. To determine the roles of lake primary productivity and carcass-derived nutrients in influencing sockeye production (e.g., Schmidt et al, 1998).

Methods

Methods relevant to the 2004 fieldwork and subsequent laboratory analyses are described here. Coring is conducted in deep basins away from areas of steep topography determined from lake bathymetry. Such sites are chosen to avoid complications from processes such as turbidites and gravity flows. Multiple cores are generally obtained in each lake to ensure that representative records are produced. High quality surface cores were obtained from each lake with a gravity or light-weight hammer corer designed for sampling unconsolidated sediments and obtaining an undisturbed sediment-water interface. The relatively thick and dense Katmai ash (1912) is present in the top 10 cm in many lakes, presenting a challenge to obtaining undisturbed cores. The surface cores were continuously sampled in the field at 0.5 - 1.0 cm increments using a precision extruder until the sediments were consolidated enough for safe transport to the laboratory. Longer cores were obtained using hammer or percussion coring systems (typical lengths ~2-5 m) at the same site. Long cores selected for detailed study are sampled continuously at 1 cm increments.

Coring methods and subsequent analyses have been divided into two levels depending on the time frame of interest for a given system. Detailed analyses of last ~500 years (referred to as “Level 1” for this project) are obtained by high resolution sampling and analysis (0.5 – 1.0 cm); the length of core and coring device for this analysis vary from lake to lake depending on factors such as sedimentation rate. Analyses covering longer time frames (~500 - 12,000 years) are conducted at lower resolution on longer cores (referred to as “Level 2” for this project). The records obtained from different cores can typically be spliced together using stratigraphic markers such as volcanic ash layers (Finney et al., 2002).

The cores are described using standard sedimentological techniques (PALE, 1994). Physical properties measured on each sample include water content, and wet and dry bulk density. These measurements allow for determination of sediment compaction, necessary for developing accurate sediment chronologies. Magnetic susceptibility is measured on each sample to determine the distribution of volcanic ash layers and to provide other stratigraphic information. Magnetic susceptibility is a measure of the degree to which sediments may be magnetized and is expressed as SI units (SI=standard international, a unitless measure). Magnetic susceptibility is run in two ways. A pass-through ring sensor can be run on whole unopened cores, and individual samples in vials can also be analyzed. Magnetic susceptibility is a useful tool for correlation between cores taken from the same lake or even cores from different lakes in the same region. Dating of the cores will be determined by both radiometric (^{14}C [radiocarbon] and ^{210}Pb analysis) and tephrachronologic (tephra stratigraphy) methods. Tephra layers may be common given the close proximity to active volcanoes; chronologies will be refined if tephras of known events (i.e., Katmai 1912) are found. Tephrachronology will assist dating and between lake correlation. Downcore analyses of carbon, nitrogen, $\delta^{13}C$ and $\delta^{15}N$ is conducted on a Finnigan Delta Plus mass spectrometer coupled with an elemental analyzer. Organic matter and carbonate content is determined by the loss on ignition (LOI) technique.

Results and Discussion

Fieldwork for this project continued during 2004. In June 2004, cores were obtained from Nonvianuk, JoJo, Devil's Cove, Hammersly, Murray, Klosterman and Pringle Lakes in the Katmai and Alagnak National Park Units. In September 2004, Kontrashibuna Lake was cored in the Lake Clark National Park. In addition, through collaboration with the U.S.G.S. and Northern Arizona University, sediment samples were obtained from Cresent Lake in the Lake Clark National Park, also cored in 2004. These lakes were selected to study research questions focused on sockeye salmon colonization timing and population variability (Table 1).

Table 1. Summary of lakes cored in 2004, including National Park Unit, level of analyses and main research questions.

Alagnak National Park Unit:
Nonvianuk Lake (Level 2): Sockeye salmon population variability

Katmai National Park Unit
JoJo Lake (Level 2): Timing of isolation
Hammersly Lake (Level 1): Sockeye salmon population variability
Murray Lake (Level 1): Sockeye salmon population variability
Devil's Cove Lake (Level 2): Timing of isolation
Klosterman and Pringle Lakes (informal names) (Level 2): Control

Lake Clark National Park Unit
Crescent River (Level 2): Sockeye salmon population variability
Kontrashibuna Lake (Level 1): Control

Different coring devices were used depending on objectives and water depth, and multiple cores were obtained from each lake. The coring device, location, water depth and core length are summarized in Table 2. The cores are stored in cold rooms at the University of Alaska Fairbanks at ~4°C. At least one core from each lake has been "opened" (split lengthwise) and described. Sampling and laboratory analyses are in progress. The sections below describe preliminary laboratory results for each lake carried out in 2004.

2004 CORES – Preliminary results

NONVIANUK LAKE

Four cores were recovered from Nonvianuk Lake ranging in length from 40 – 436 cm. In the longest percussion core, the sediments grade from green-brown pelagic mud to grey glacial sediment, about half way down the core (Fig. 1). Sources of glacial sediment are minor today, and were also probably minor during the Little Ice Age. This suggests that this core may have recovered sediment from the deglacial period following the last ice age. Consistent with this idea, alder pollen is absent near the sediment transition. Pollen records from the region (Brubaker et al. 2001) suggest that following the last ice age, alder did not appear until about 9,000 yr BP. Thus the absence of alder pollen at depth suggests the sediments are older than ~9,000 yr BP. Radiocarbon analyses are in progress to provide better chronologic information. The hammer and percussion cores can be easily correlated based on tephras (Fig. 2). The carbon-to-nitrogen weight ratio (C/N) of the organic matter is low and fairly constant ~8, optimal for salmon reconstructions. The preliminary $\delta^{15}N$ data on PC-1 ranges from ~3.5 – 6, indicating promise for reconstructing past salmon runs (Fig. 3). Relatively higher values are found between 50 – 100 cm, and below 250 cm.

JOJO LAKE

Three cores up to 300 cm in length were recovered from JoJo Lake. The Katmai 1912 ash was found at about 6 cm depth, and is the thickest ash observed in the cores. Sediments from the bottom of the JoJo lake core are of a glacial character (Fig. 4). Pollen analysis from a sample below the transition indicates the presence of alder, and thus the core is probably less than 9000 yr BP. Radiocarbon analyses are in progress to better determine the chronology of the core. In contrast to Nonvianuk, the glacial sediment could indicate the time when this lake was connected to the nearby glacial streams via post-glacial geomorphic processes. Such processes would connect the presently closed-basin lake to the ocean, and thus could allow salmon colonization. The C/N of the organic matter is low and fairly constant with values averaging ~8 (Fig. 5), suggesting the dominance of aquatic sources throughout despite major lithologic changes. The preliminary $\delta^{15}N$ profile for PC-1 (Fig. 6) shows low values at the top and two downcore intervals with higher values. The zones with higher values may suggest periods of salmon runs in the past.

HAMMERSLY AND MURRAY LAKES

Three cores were recovered from Hammersly Lake ranging from 21 – 158 cm in length. Our initial work focused on the longest core HC-3. The organic matter (LOI) profile (Fig. 7) reveals the presence of 2 major tephra layers (Katmai 1912, and probably the older tephra previously identified in Brooks and Naknek Lakes), and overturned beds below about 88 cm. This is a similar sequence to that observed in Brooks Lake, which contained a major debris flow unit below these 2 tephras. The similarity of the Brooks and Hammersly records could indicate a major regional seismic event about 2000 yr BP. The C/N data are slightly higher than Nonvianuk and JoJo Lakes, averaging ~10. Such values are still indicative of aquatic sources. The preliminary $\delta^{15}N$ data (Fig. 8) ranges from ~1.5 – 4, averaging about 2.8. These values are lower than those found in Nonvianuk Lake.

A 114 cm long core was recovered from Murray Lake. The core is dominated by a thick Katmai ash unit. Further analyses have not been conducted to date.

KLOSTERMAN AND PRINGLE LAKES

Three cores were recovered from Klosterman Lake (informal name) ranging up to 200 cm in length. This is a control, non-anadromous lake located near JoJo Lake. Several of the ash layers can be correlated between the lakes, indicating they cover much of the time frame. Sampling and analysis of the core is in progress. Pringle Lake (informal name) is a control lake located between Brooks and Naknek Lakes. A reconnaissance bathymetric survey indicated that the lake was shallower than anticipated (maximum depth ~ 4m), making it less than optimal for control purposes. The sediments contain some sand and abundant plant macrofossils. Further analyses have not been conducted to date.

DEVIL'S COVE LAKE

A 16 cm gravity core and a 157 cm hammer core were recovered from Devil's Cove Lake. The core contains several tephra units, probably including the Katmai 1912 unit. Further analyses have not been conducted to date.

CRESCENT RIVER LAKE

The U.S.G.S. and Northern Arizona University cored Cresent River Lake in the summer of 2004. Two percussion and paired gravity cores were obtained, one proximal to the input stream, and one is a distal location. Samples from the distal gravity core have been provided to this project, and sample preparation is in progress. A gravity core from the lake was previously obtained in 1998. Preliminary C, N and stable isotope results were conducted on 3 samples from this core. The C/N ratio averaged about 11, and the $\delta^{15}N$ averaged 3 for these samples.

KONTRASHIBUNA LAKE

Four cores were recovered from Kontrashibuna Lake up to 275 cm in length. The cores consist of banded and laminated sediments grey-brown to green-brown in color. Sampling of the longest core (PC-1) is complete, and LOI and magnetic susceptibility analyses are nearly complete, and stable isotope analysis has begun.

2003 CORES – Update of analyses during 2004

BROOKS LAKE

Two hammer cores and one percussion core were recovered from Brooks Lake during year 1. Progress continued on these cores in 2004. All of the Brooks Lake cores have been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI). Laboratory work has focused on core HC-1, the longer of the hammer cores at 187 cm. An additional radiocarbon date was obtained (Table 3) consistent with the basal date (179 cm) of about 3730 yr BP (Fig. 9). The C/N ratio of the Brooks Lake sediments are relatively constant, averaging ~10, excluding the debris flow unit. Detailed $\delta^{15}N$ analysis has been conducted for the HC-1 core (Fig. 10). The $\delta^{15}N$ values are fairly low, averaging about 2.5. However, the data has significant variability, with $\delta^{15}N$ values ranging from 1 – 3.5. The data show interesting century-scale cycles, as well as longer-term fluctuations. The record is being extended through analysis of the longer companion percussion core. Additional radiocarbon samples have been obtained from both cores, and have been sent to Lawrence Livermore National Laboratory for AMS radiocarbon analysis. Detailed analysis on lake productivity for these cores will be done on this core as part of Morgan Peterson's M.S. thesis.

NAKNEK LAKE

Two hammer cores and one percussion core were recovered from Naknek Lake in 2003. All of the Naknek Lake cores have been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI). The sediments are dominated by glacially-derived lithogenic material, but diatoms, other micro and macro fossils, and tephras are present. Using the two prominent tephras, the hammer and percussion cores have been correlated to develop a composite record for the lake which spans the upper ~450 cm. The magnetic susceptibility profile (Fig. 11) shows one prominent peak (brown tephra) below the Katmai 1912 tephra. A terrestrial macrofossil sample near the bottom of the core yielded a calibrated AMS radiocarbon age of ~1250 AD (Table 3). The age depth relationships based on the core top age, Katmai 1912 tephra and basal radiocarbon age suggest the brown tephra dates to about 1600 AD, similar to the age estimate for this similar tephra in Brooks Lake (Fig. 9).

The C/N data for the Naknek sediments are low and fairly constant, averaging about 7.5. This indicates the dominance of aquatic-derived organic matter. The $\delta^{15}N$ profile (Fig. 12) shows relatively high values, averaging ~4.5. The data show considerable variability, ranging from ~2.5 – 5.5. The lowest values are observed during the last ~50 years. Detailed analysis on lake productivity for these cores will be done on this core as part of Morgan Peterson's M.S. thesis.

SURPRISE LAKE

Seven cores were recovered from Surprise Lake in 2003 representing 5 different sites. All the cores from Surprise Lake have been opened, described and correlated. LOI and SI analysis is nearly complete for the set of cores. The cores have a generally consistent stratigraphy, as a characteristic set of tephras is found in all cores. A surface unit that consists of orange-red sandy muds overlies a coarse tephra that occurs between 10-50 cm, depending on core site (Fig. 13). A second tephra unit with similar characteristics in all the cores is found between 70 - 105 cm (Fig. 13). Below the orange surface unit, the non-tephra sediments consist of orange-brown to brown-black sandy, mud. Diatoms are present, as well as occasional organic macrofossils. The relatively consistent stratigraphy recorded in the widespread cores is encouraging that they contain a representative recent history of the lake. Based on the core correlations core HC-5 contains the oldest sediments. Thus Core HC 5 (and companion surface core HC 6) were selected for detailed analysis.

A near basal sample from core HC-5 yielded a calibrated radiocarbon age of ~1450 AD (Table 3). A simple age model was constructed based on the coring date and the calibrated basal radiocarbon date (Fig. 14). This model suggests that the upper tephra is likely the 1931 Aniakchak volcanic event consistent with its physical properties (T. Neal, personal communication, 2003). The C/N data for the core show great variability with some high values (range 8 - >20). The high values may be due to terrestrial organic material or high carbonate content. Laboratory analyses to assess these factors are in progress. Stable isotope ($\delta^{15}N$) results (Fig. 15) show large variability, ranging from ~1 – 5. The relatively high values may suggest contributions of salmon-derived nutrients. The $\delta^{15}N$ profile shows a general trend of increasing values over the past ~500 years. This may suggest colonization and run size increase since the major volcanic event about 500 years ago.

MESHIK LAKE

Four cores were recovered from Meshik Lake in 2003. The cores have been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI). The cores have been correlated based on tephra and other characteristics, and interpreted in terms of environmental history (Fig. 16). The sediments consist of lacustrine diatom and organic rich muds overlying basal gravels and/or peats, with several prominent tephras. The basal appear to contain the lake initiation event, and a series of AMS radiocarbon dates in several cores is consistent with this event occurring at about 1700 yr BP (Table 3). A set of samples have been run for C, N and stable isotope analysis. The C/N profile (Fig. 17) shows higher values below about 260 cm, an interval interpreted to represent terrestrial and flood deposits. The higher values are consistent with a dominance of terrestrial organic material in this unit. The stable nitrogen isotope ($\delta^{15}N$) profile shows low values in the terrestrial unit (FIG. 18). Highest values (~2) are found in the upper part (above 140 cm) of the lacustrine sediment unit, which starts at about 260 cm.

Synthesis of Core $\delta^{15}N$ Data

Figure 19 show the distribution of the sedimentary $\delta^{15}N$ and C/N data in selected cores that are representative of the range of data of the study sites. The Surprise Lake data is not included, as additional analysis is required to determine the cause of the high C/N ratios, which could indicate contributions from carbonate minerals (which would not effect the $\delta^{15}N$ values). Otherwise, the characteristics of the C and N data suggest that the values represent those of the lake organic matter. The C/N ratios are indicative of organic matter source, with low values (<10) characteristic of aquatic sources, and higher values (~ >20) typical of terrestrial organic matter. Most of the study lakes appear to be dominated by aquatic organic matter, as they have C/N values less than ~11 (Fig. 19). The exceptions are the debris flow unit in Brooks Lake, and the pre-lake terrestrial unit in Meshik Lake. In utilizing bulk sediment $\delta^{15}N$ data to reconstruct salmon runs, the assumption is the values represent aquatic organic matter as the salmon-derived nutrients high in $\delta^{15}N$ enter the lake nutrient pool, and are taken up by lake phytoplankton and subsequently sedimented (Finney et al. 2000). The range in $\delta^{15}N$ values in samples with low and relatively constant C/N ratios, could be due to due to variable contributions of salmon-derived nutrients. Other factors can contribute $\delta^{15}N$ variability in non-salmon lakes, however (Finney et al. 2000). The data in Figure 19 suggests that some lakes in the study, such as Naknek and Nonvianuk, may be highly suitable for reconstructing past salmon runs. The relatively high values in JoJo Lake are surprising. Some of the intervals with high $\delta^{15}N$, as discussed, may be due to periods of salmon runs in the past. The relatively high core top values indicate that watershed specific factors can influence the baseline $\delta^{15}N$ values. The mean $\delta^{15}N$ values in 33 non-salmon lakes in Alaska averaged 1.5 +/- 0.9. A critical assessment of non-salmon factors that could influence $\delta^{15}N$ variability will be required in interpreting the data of this project. Analysis of control lakes is one method that will be further investigated.

Plans for Coming Year

Tasks to be completed during 2005 include:

1) Open and describe the remainder of the 2004 cores.
2) Complete the basic analysis of all the cores recovered to date (water content, wet and dry bulk density, and LOI).
3) Refine or establish radiocarbon chronologies for all lakes.
4) Refine chronologies using detailed tephra analysis in collaboration with AVO and UAA colleagues.
5) Better date and examine evidence of the possible major seismic event at ca. 2000 BP.
6) Complete stable isotopic (i.e. $\delta^{15}N$) analyses for the cores recovered in 2003 and 2004.
7) Assess $\delta^{15}N$ data in terms of salmon escapement.
8) Reconstruct lake paleoproductivity using multiple proxies.
9) Assess salmon population reconstructions in terms of paleoenvironmental change.
10) Assess lake paleoproductivity variability in terms of salmon abundance fluctuations and paleoenvironmental change.
11) Conduct the final fieldwork in 2005. Detailed planning, with Park Service logistical concerns in mind, will be finalized well before the initial fieldwork in late June - July, in consultation with Park Service personnel.

The dating and N-isotopic results will allow a more detailed assessment of the data in terms of past salmon abundance. We will attempt to calibrate time-series of sedimentary $\delta^{15}N$ with historical records of escapement and estimate pre-historic escapements from downcore changes in $\delta^{15}N$. Paleoproductivity will be assessed from downcore analyses of organic carbon, biogenic silica and organic $\delta^{13}C$. We will also begin initial comparisons of the salmon abundance and lake productivity time-series with published paleoclimatic and paleoceanographic data, as well as with paleoclimatic and paleoenvironmental data determined from analysis of the sediment cores recovered as part of this project and the closely related project by Heiser (UAA). Historical climatic and oceanographic data go back ~100 years. Sources of paleoenvironmental data include coastal tree rings, glacial advance-retreat chronologies, coastal lake sediment core data and North Pacific Ocean sediment core data (e.g., Mann and Hamilton, 1995; Mann et al., 1998; Wiles and Calkin, 1994; Wiles et al., 1998).

Masters student Morgan Peterson completed her research proposal in the fall of 2004, and submitted it to SWAN personnel. Her plans involve a comparison of lake productivity and salmon abundance in a set of lakes of different types (clear - Brooks, glacial - Naknek, control - Klosterman, and mixed/unknown - JoJo) over the past several thousand years using multiple proxies (diatoms, stable isotopes, geochemistry). She has made significant progress in the lab, with the basic lab work for most cores complete or well underway. The stable isotope work will be completed in 2005, and the diatom work will begin. She is on track to complete her thesis in 2006, the final year of this project.

Acknowledgements

Many people helped in successfully completing the fieldwork, including T. Jones, A. Krumhardt and M. Peterson. The assistance of the Park Service staff in King Salmon was of great help. A. Krumhardt, M. Odell, K. Streeter, M. Peterson, T. Borland and S. Gaylor assisted in laboratory analyses. Finally, thanks to L. Bennett and T. Hamon for helping to facilitate this project, and the Inventory and Monitoring Program of the National Park Service for funding.

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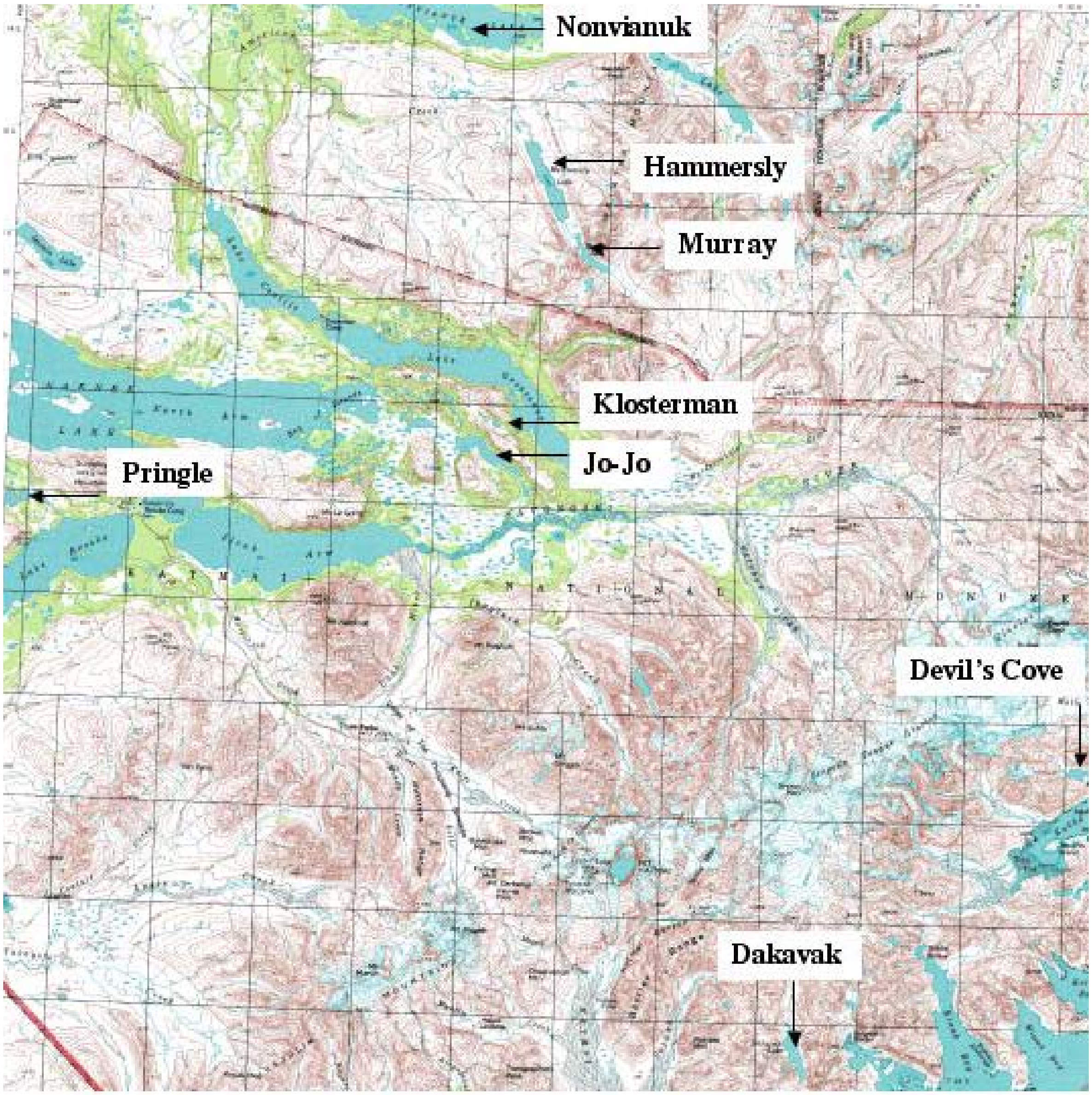

Location of lakes visited during the 2004 field season, Southwest Alaska Network, National Park Service.

Table 2. Sediment core and limnological sampling information, Katmai, Alagnak and Lake Clark National Park Units, 2004.

Lake	Core Type	Location	Water Depth	Core Length	Extruding Notes	Limnology samples	Remarks
Nonvianuk Lake	HC-1	58° 58.809’ 155° 13.902’ Mt. Katmai D-4	46 m	159 cm	0-14 cm @ 0.5 cm intervals		Not cut into sections, 14-159 in tube
	HC-2	58° 58.806’ 155° 13.906’	45 m	239cm		Secchi depth (826 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water Soil sample	Windy, rain, lake surface choppy. Overtopped tube Cut core into: Sec 1 : 0-90 Sec 2: 90-239
	PC-1	58° 58.808’ 155° 13.896’	45 m	436 cm			Cut core into: Sec1: 0-150 Sec 2: 150-300 Sec. 3: 300-436
	Surface (HC)	58° 58.808’ 155° 13.896’	45 m	40 cm	0-4 cm @ 0.5 cm intervals		
JoJo Lake (deep basin)	HC-1	58° 36.446’ 155° 12.908’ Mt. Katmai D-4	33 m	220 cm	0-6.5 cm @ 1 cm intervals.	Secchi depth (501 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water	Degassing evident.
	PC-1	58° 36.465’ 155° 12.912’	34 m	300 cm			Cut off disturbed part of top, then cut core into 2 ~150 sections
	Surface (HC)		34 m	47 cm	0-11 cm @ 0.5 cm intervals 11-13 cm @ 1 cm intervals (into Katmai ash)		After extruding, remainder discarded. Katmai ash around 10-10.5

Lake	**Core Type**	**Location**	**Water Depth**	**Core Length**	**Extruding**	**Limnology samples**	**Remarks**
JoJo Lake (shallow basin)	HC-2	58° 37.346' 155° 14.712'	10 m	N/A			Did not save core, shorter record than HC-1, based tephra distributions. Quality questionable
Dakavak Lake (from float plane)	N/A	58° 05.823' 154° 40.628' Mt. Katmai A-3	52-76 m			Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water Soil sample	No coring - Katmai ash too thick
Devil's Cove (from float plane)	HC-1	58° 21.168' 154° 14.502' Mt. Katmai B-1	53 m	157 cm	0-4 cm @1 cm intervals	Secchi depth (246 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water	
	G-1			16 cm	0-16 cm @ 0.5 cm intervals		
Murray Lake (from float plane)	HC-1	58° 46.928' 155° 04.161' Mt. Katmai D-4	41 m	114 cm		Secchi depth (764 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water	Difficulty in coring and retrieving. Appeared to recover mainly Katmai ash.

Lake	Core Type	Location	Water Depth	Core Length	Extruding Notes	Limnology samples	Remarks
Hammersly (from float plane)	HC-1 (surface)	58° 51.507' 155° 08.930' Katmai D-4	27 m	21 cm	0-2.5 @ 0.5 intervals 2.5-9.5 @ 1 cm intervals	Secchi: 1064 cm (TJ) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1.5L) $\delta^{18}O$ - Lake water	Dense Katmai ash disturbed surface sediments.
	HC-2			139 cm	0-7 cm @ 1 cm intervals		7-139 in tube
	HC-3	58° 51.502' 155° 08.915'	26	158cm	0-8 @ 1 cm intervals		8-158 in tube
Klosterman (informal name) (from float plane)	HC-1	58° 38.166' 155° 12.434' Mt. Katmai C-4	15 m	~1.2 m		Secchi depth (445 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water	Cut off soupy top.
	HC-2			~2 m			Overtopped. Cut off soupy top @ Katmai
	HC-3 (surface)				0-9 cm @ 0.5 cm intervals		Top may be disturbed by Katmai ash.
Pringle (informal name) (from float plane)	HC-1	58° 33.592' 155° 58.075' Mt. Katmai C-6	4 m	150 cm	0-5 cm @ 1 cm intervals	Secchi depth (>400 cm; could see bottom) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water Soil sample Potamogeton sample	

Lake	Core Type	Location	Water Depth	Core Length	Extruding Notes	Limnology samples	Remarks
Kontrashibuna Lake	HC-0	60° 11.069’ 154° 09.199’	46 m	134 cm		Secchi depth (325 cm) Surface water CO_2 Zooplankton (vertical tow) Phytoplankton (POM) filter chlorophyll *a* (1L) $\delta^{18}O$ - Lake water	Test core, overpenetrated but kept.
	HC-1	60° 11.069’ 154° 09.199’	46 m	220 cm			Sediment-water interface disturbed. Cut 20 cm off core top
	HC-2	60° 11.115’ 154° 09.182’’		107 cm	0-6 cm @ 0.5 cm intervals		Surface core
	PC-1	60° 11.112’ 154° 09.207’		275 cm			Cut off disturbed top, then into 2 sections

HC = Hammer core
PC = Percussion core with piston
Livingston: Corer can recover maximum of 1 meter of sediment per drive from same hole.
Latitude/Longitude Data: Coordinates derived from recreational grade GPS (Garmin GPS 40 or Garmin GPS Map 76s with an external antenna that averaged >30 seconds). Data has not been differentially corrected. All positions are in degrees decimal minutes and NAD27 datum.

Limnological samples for each lake included:
Lake water $\delta^{18}O$ and $\delta D/H$ (deuterium to hydrogen ratio)
Zooplankton obtained by vertical net hauls for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$)
Filtered lake surface water (POM) for C, N and stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$)

Table 3. AMS radiocarbon results.

CENTER FOR ACCELERATOR MASS SPECTROMETRY

Lawrence Livermore National Laboratory - ^{14}C results

Submitter: Finney/Brown

CAMS #	Sample Name	^{14}C age	±	1 Sigma Calibrated age range
111109	Brooks HC-1 128-130	2250	110	2057 - 2355 BP
111111	Naknek PC-1 342-344	800	40	1218 - 1274 AD
111112	Surprise HC-5 231-232	435	45	1424 - 1487 AD
111113	Meshik Core C, D2 216 a	1620	60	1417 - 1562 BP
111114	Meshik Core C, D2 216 b	1595	40	1419 - 1526 BP
111115	Meshik Core C, D2 276	1845	40	1723 - 1822 BP
111116	Meshik Core D, D2 282-283	1730	40	1568 - 1695 BP
111147	Meshik Core D, D3 306-307	1845	30	1734 - 1820 BP

1) $\delta^{13}C$ assumed values of -25 according to Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977)

2) The quoted age is in radiocarbon years using the Libby half life of 5568 years and following the conventions of Stuiver and Polach (ibid.).

3) Sample preparation backgrounds have been subtracted, based on measurements of samples of 14C-free coal. Backgrounds were scaled relative to sample size.

4) Calibration using program CALIB REV4.4.2 (Stuiver, M., and Reimer, P.J., 1993, Radiocarbon 35: 215-230).

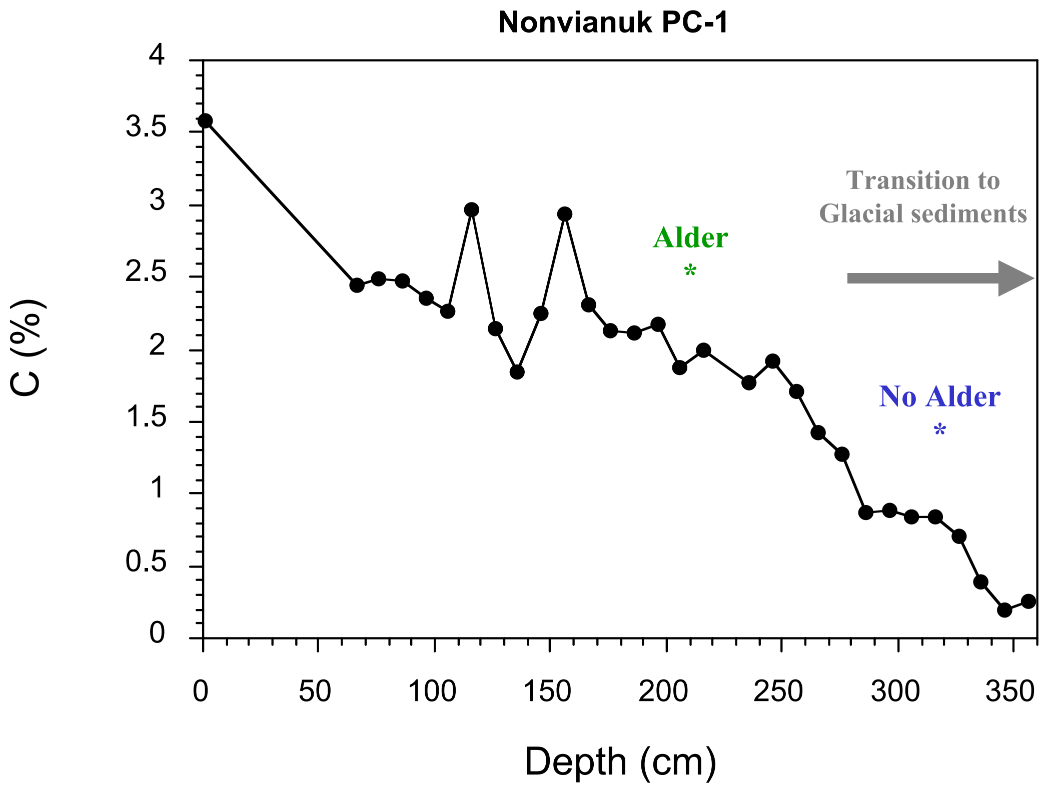

Figure 1. Percent Carbon vs. depth for core PC-1 from Nonvianuk Lake. The upper sample is from the core HC-1. Depths in PC-1 have been adjusted based on tephra correlations shown in Figure 2. The character of the sediments change from non-glacial to glacial, with a gradual transition centered between 250 and 350 cm. The lack of alder pollen around 300 cm, suggests this transition dates to more than 9000 yr BP, and likely represents deglaciation in the watershed following the last ice age.

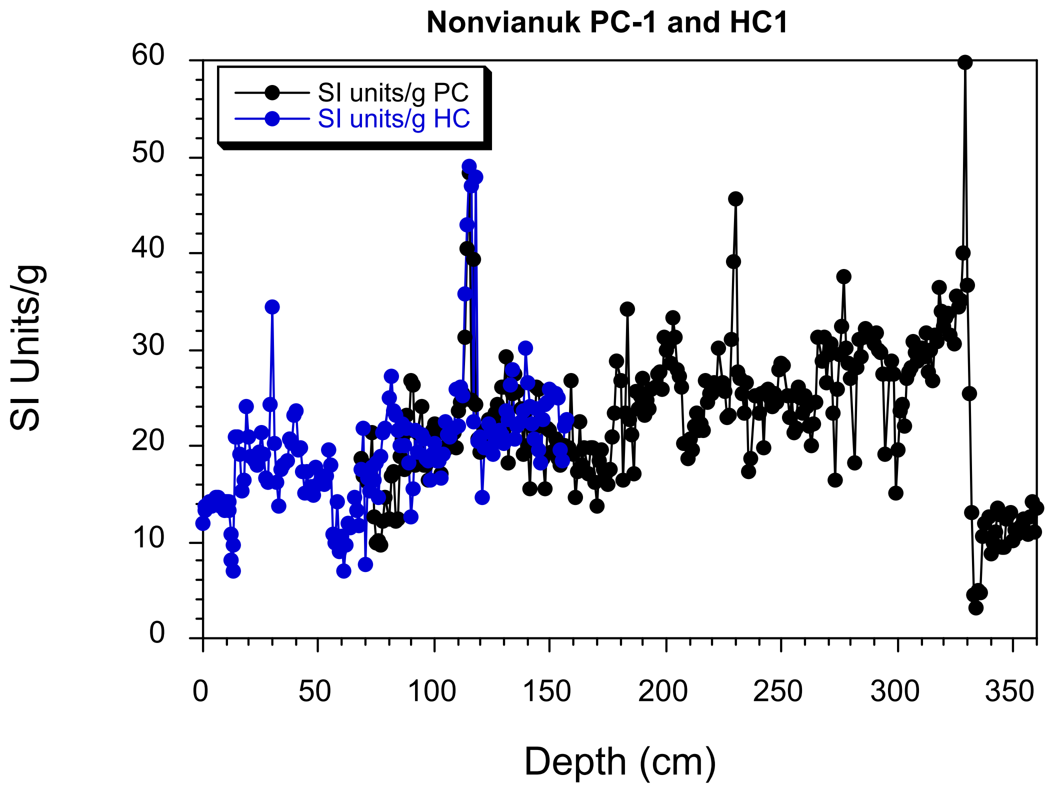

Figure 2. Magnetic susceptibility for Nonvianuk Lake cores PC-1 and HC-1. The cores are correlated at a tephra at about 115 cm in core HC-1. Depths in PC-1 were adjusted using this offset. Note the change in SI Units around 330 cm in PC-1, corresponding to glacial sediments with low carbon content.

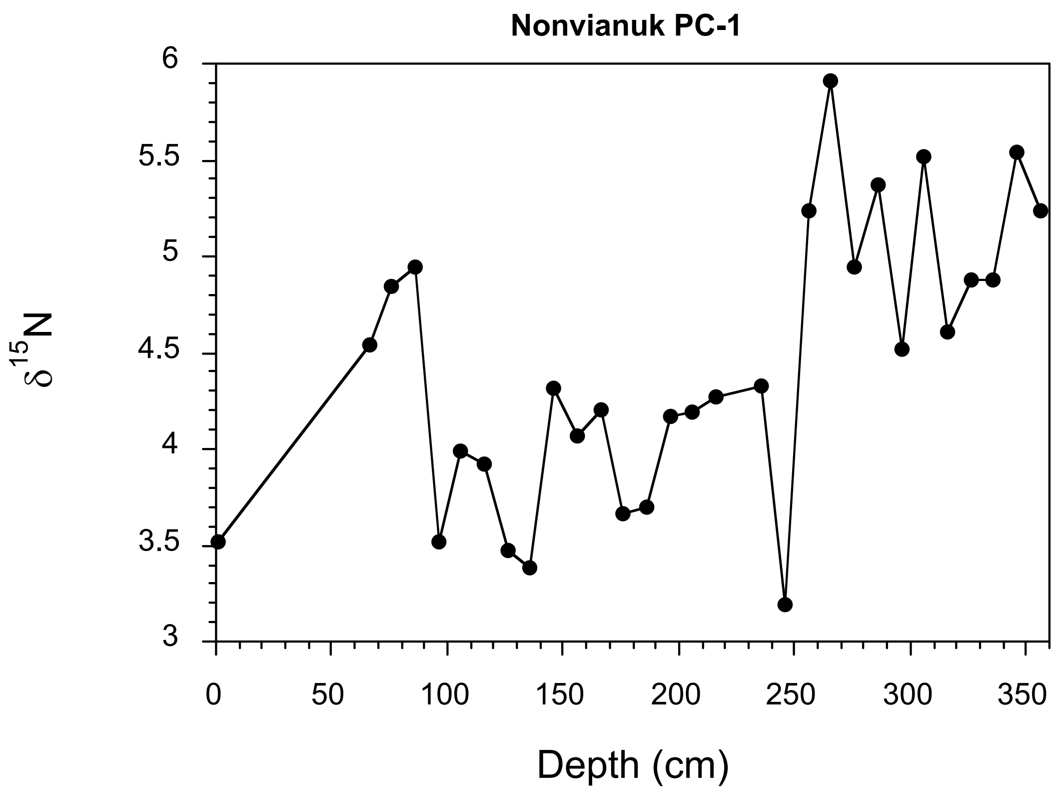

Figure 3. Stable nitrogen isotope ($\delta^{15}N$) profile vs. depth for Nonvianuk core PC-1.

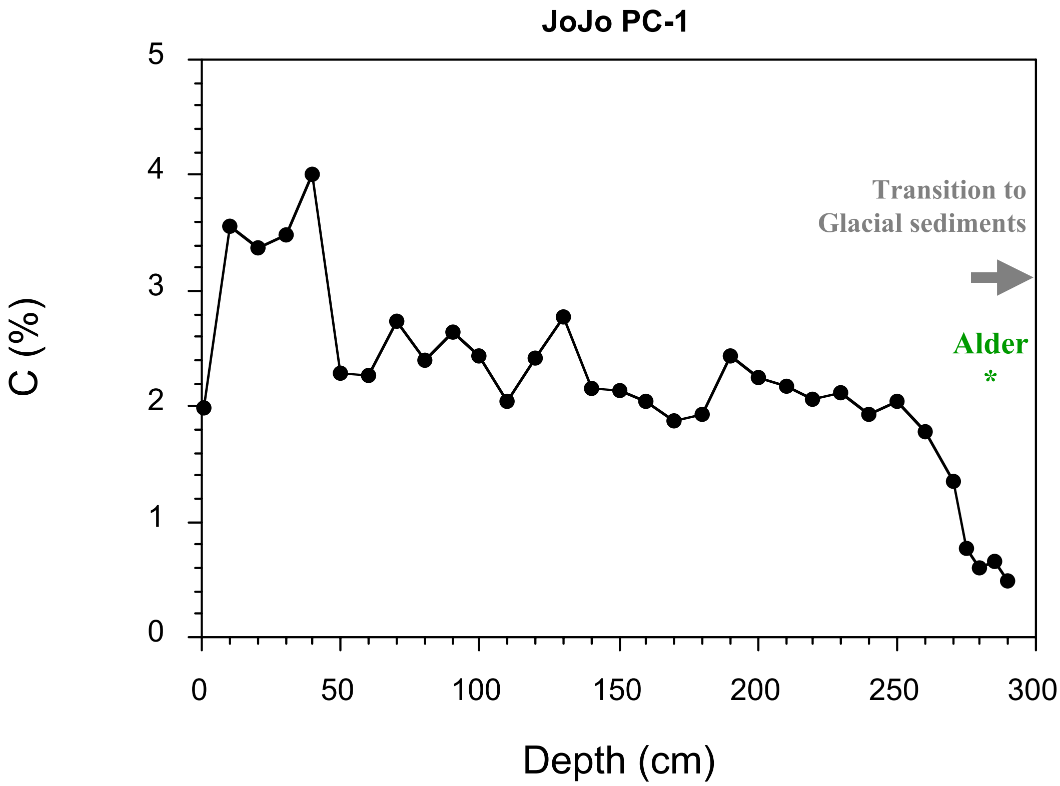

Figure 4. Percent Carbon vs. depth for core PC-1 from JoJo Lake. The character of the sediments change from non-glacial to glacial near the bottom of the core at ~270 cm. The presence of alder pollen below this transition, suggests it dates to less than 9000 yr BP, in contrast to the results from Nonvianuk Lake. The presence of glacial sediments likely represent geomorphic processes in the watershed, connecting the lake to the nearby glacial streams.

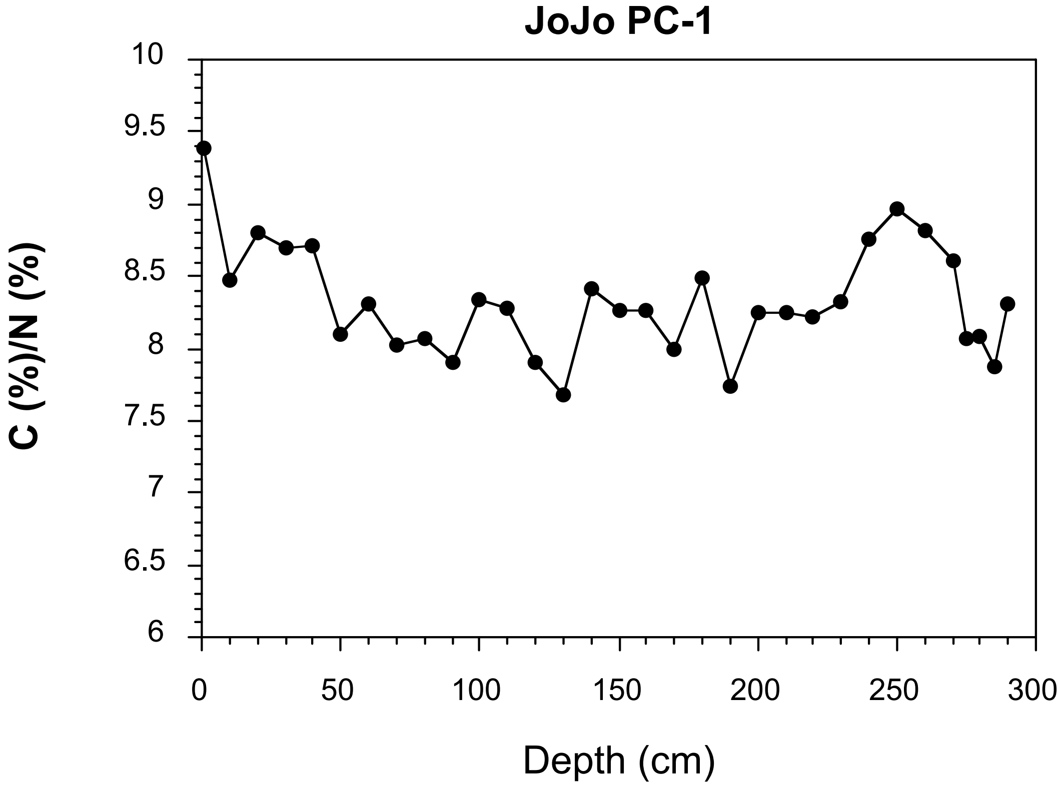

Figure 5. Profile of carbon-to-nitrogen ratio (weight percent) in JoJo core PC-1. The relatively low and constant ratio suggests the dominance of aquatic-derived organic matter.

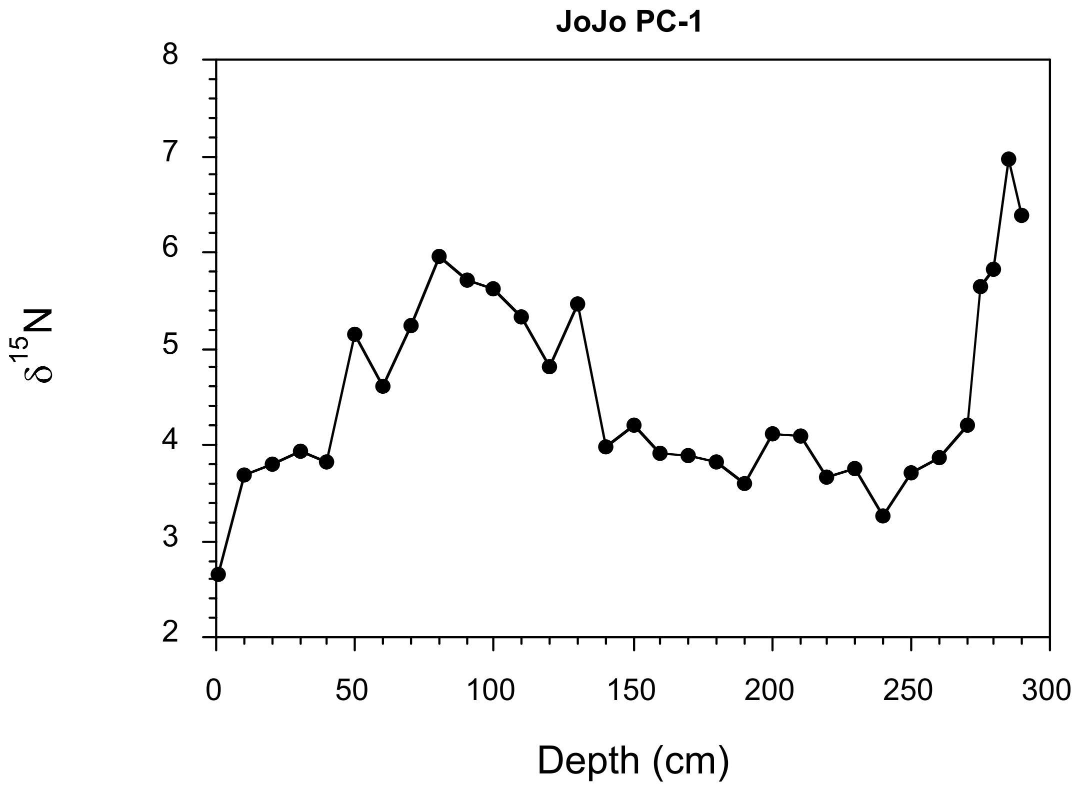

Figure 6. Stable nitrogen isotope ($\delta^{15}N$) profile vs. depth for JoJo core PC-1. Note the intervals with higher values below the surface.

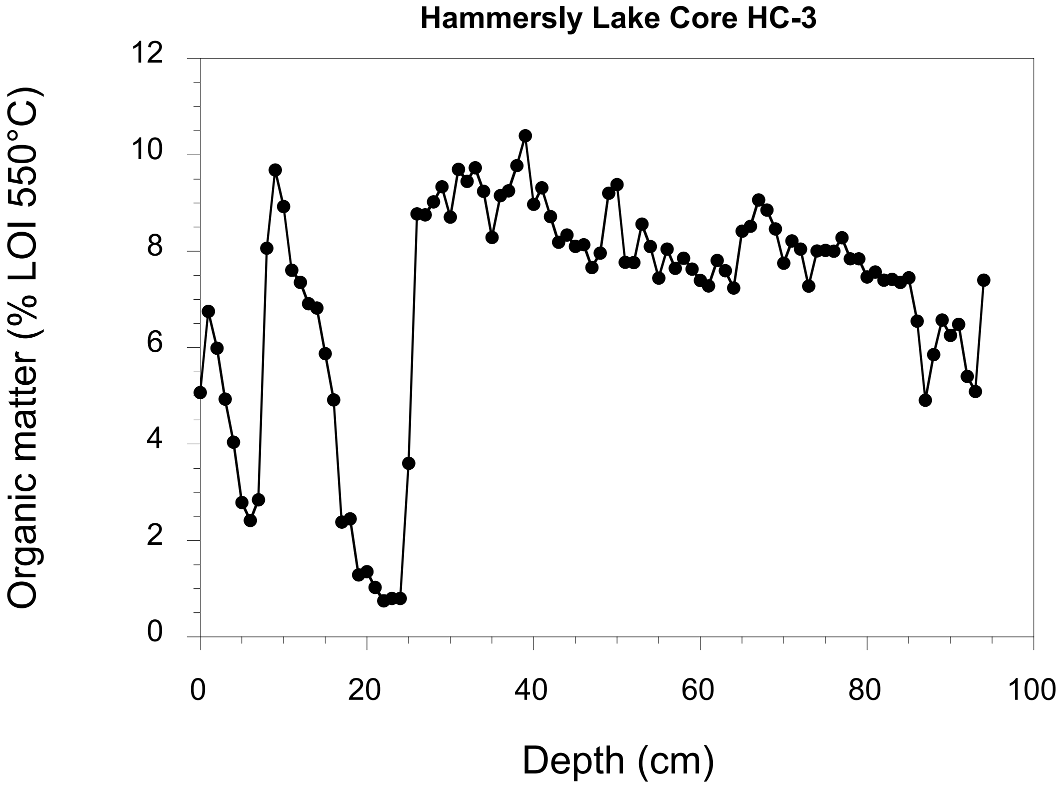

Figure 7. Organic matter (LOI) profile for the upper section of Hammersly Lake core HC-3. Two intervals with low LOI are due to the presence of tephras. The Katmai 1912 ash is located at ~8 cm, and another ash is located at 24 cm. Below about 88 cm, overturned/folded layers are observed, possibly indicating a major seismic event.

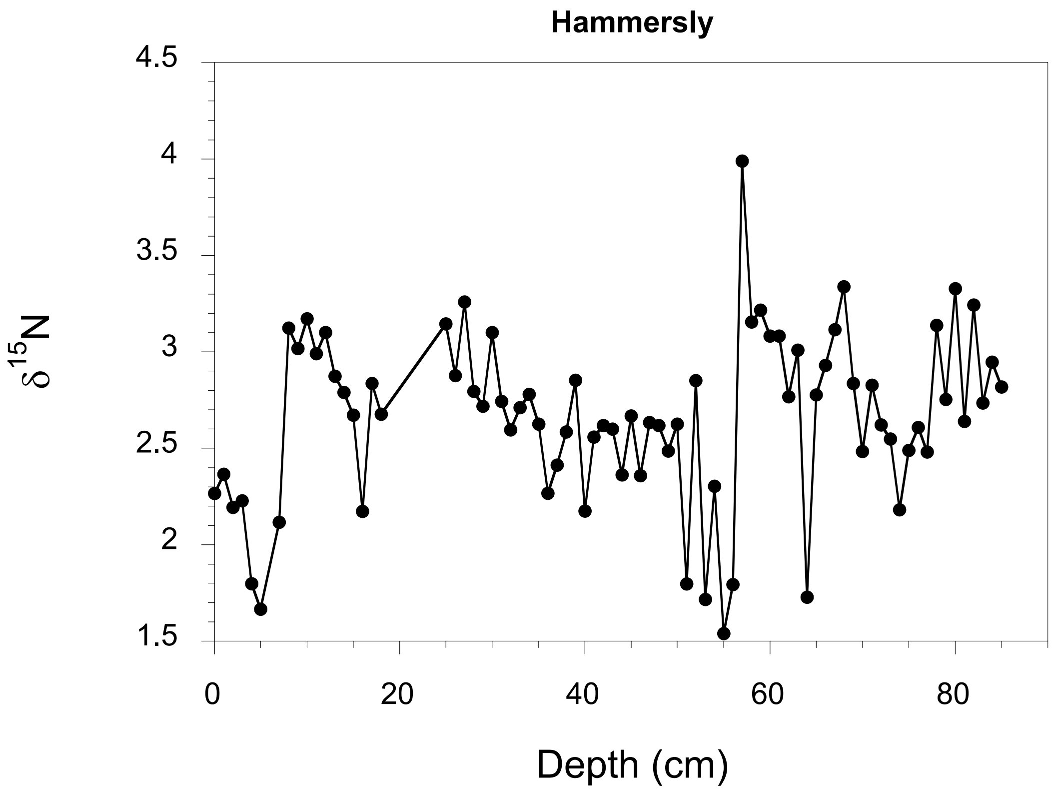

Figure 8. Stable nitrogen isotope ($\delta^{15}N$) profile for the upper section (above disturbed sediments) of Hammersly Lake core HC-3.

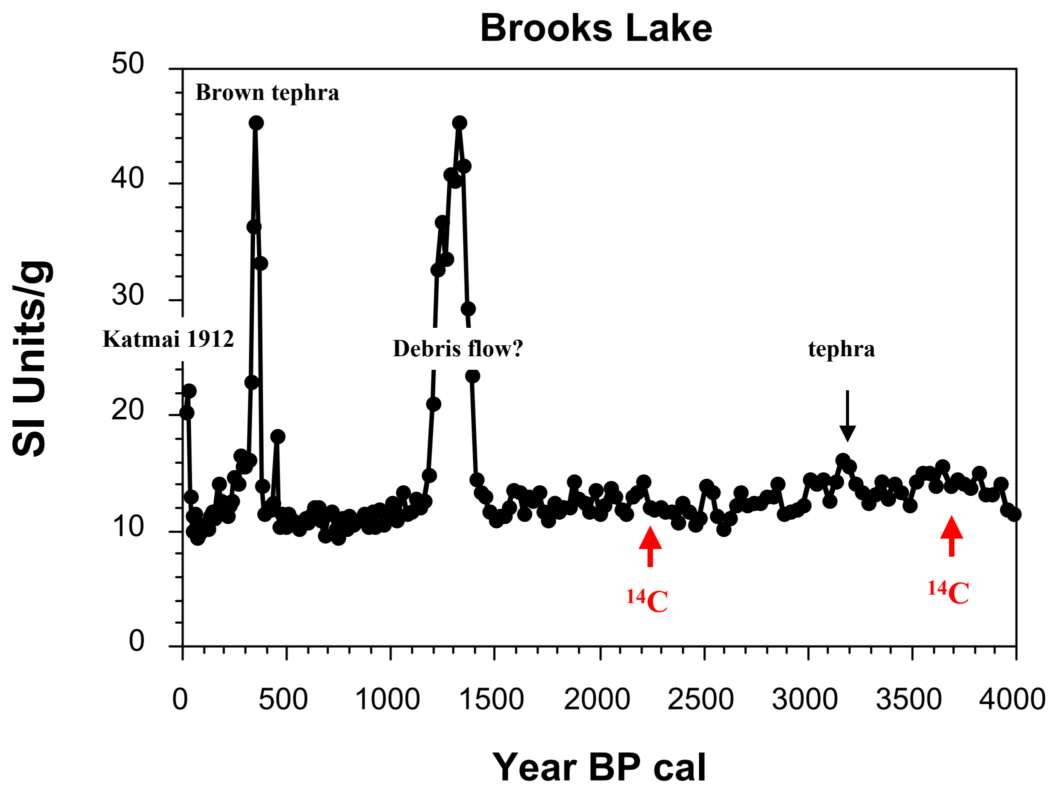

Figure 9. Magnetic susceptibility profile for Brooks Lake core HC-1 showing the locations of tephra layers, a debris flow unit, and radiocarbon dates. The SI profile is plotted vs. age, which was estimated by an age model constructed from the coring date, Katmai 1912 ash and two radiocarbon dates.

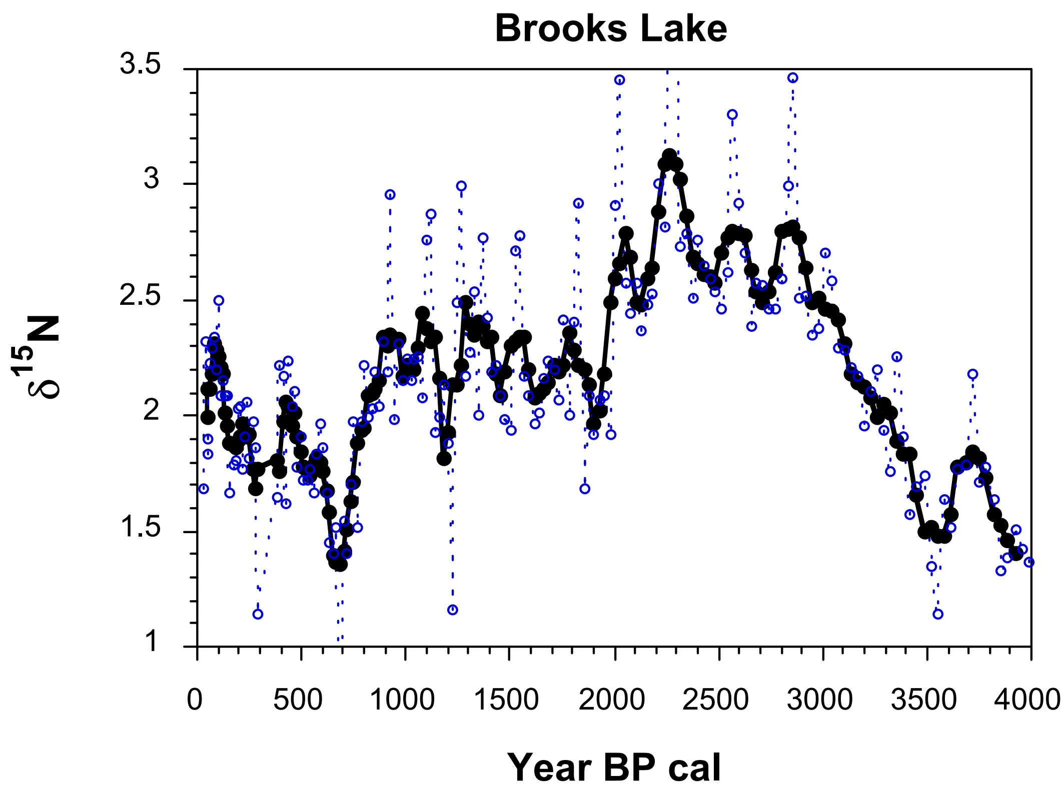

Figure 10. Stable nitrogen isotope data ($\delta^{15}N$) vs. age for Brooks Lake core HC-1. The calibrated age scale was determined as described in Figure 9.

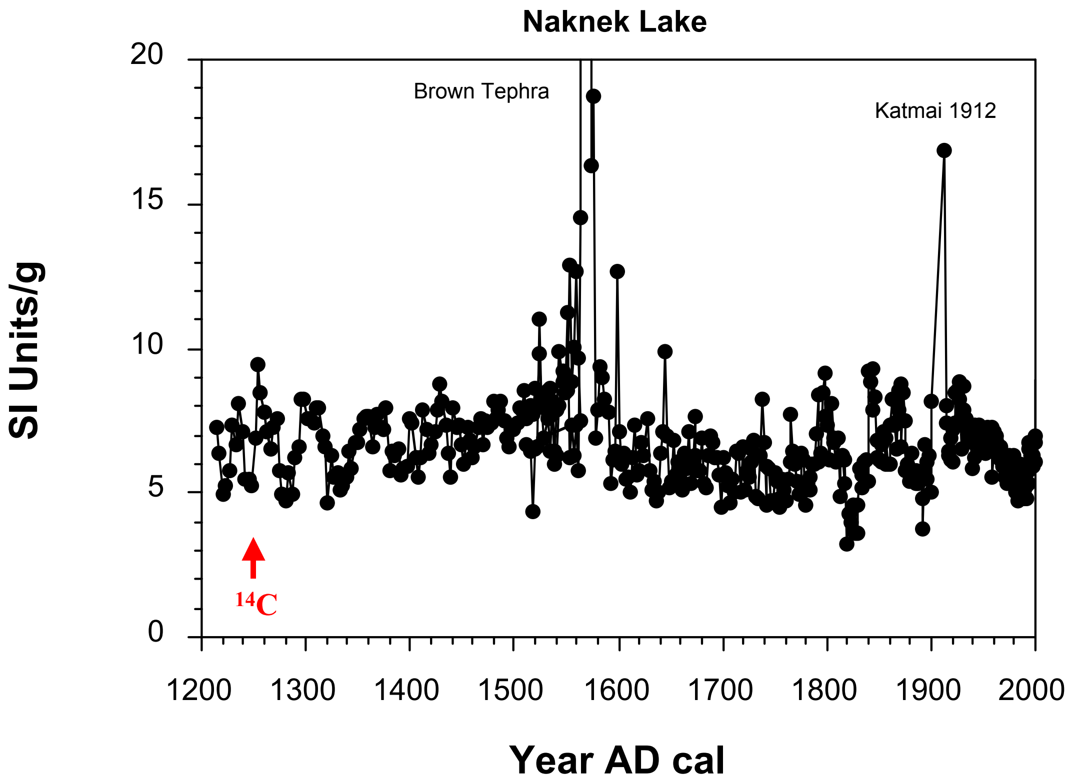

Figure 11. Magnetic susceptibility vs. age for Naknek Lake showing the locations of tephra layers and the radiocarbon date. The profile is a composite record, developed by correlating the hammer and percussion cores at the two prominent tephras. An age model was constructed from the coring date, Katmai 1912 ash and radiocarbon date.

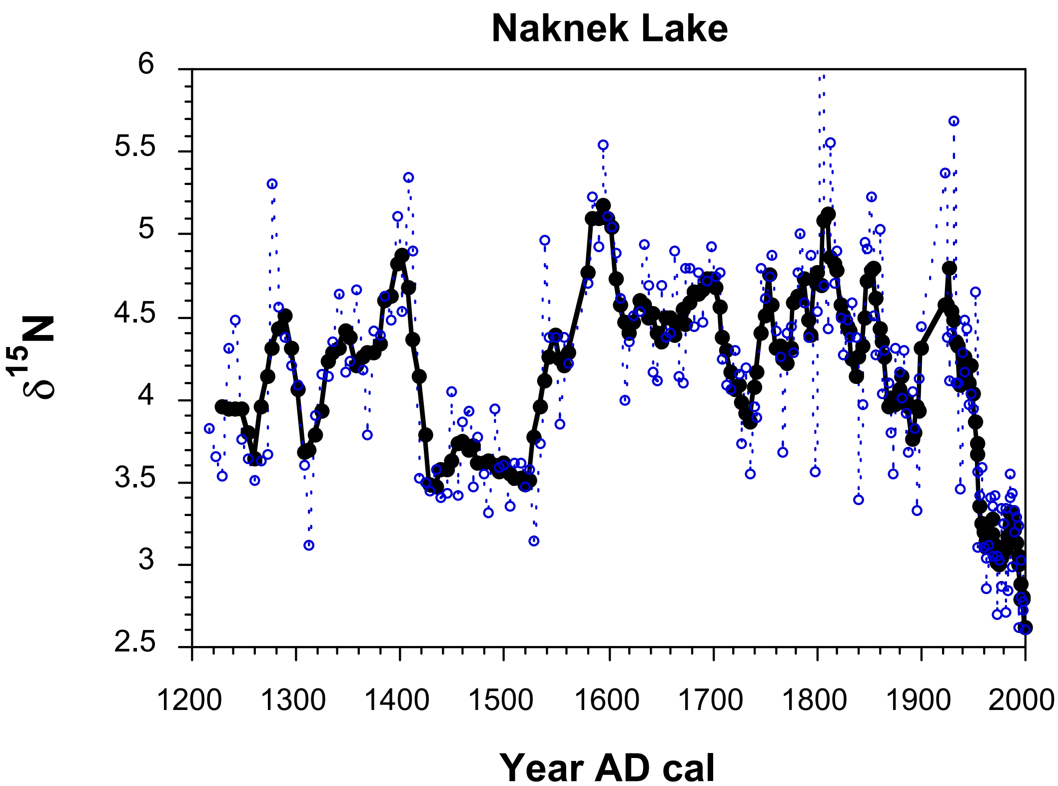

Figure 12. Stable nitrogen isotope data ($\delta^{15}N$) vs. age for Naknek Lake composite core. The calibrated age scale was determined as described in Figure 11.

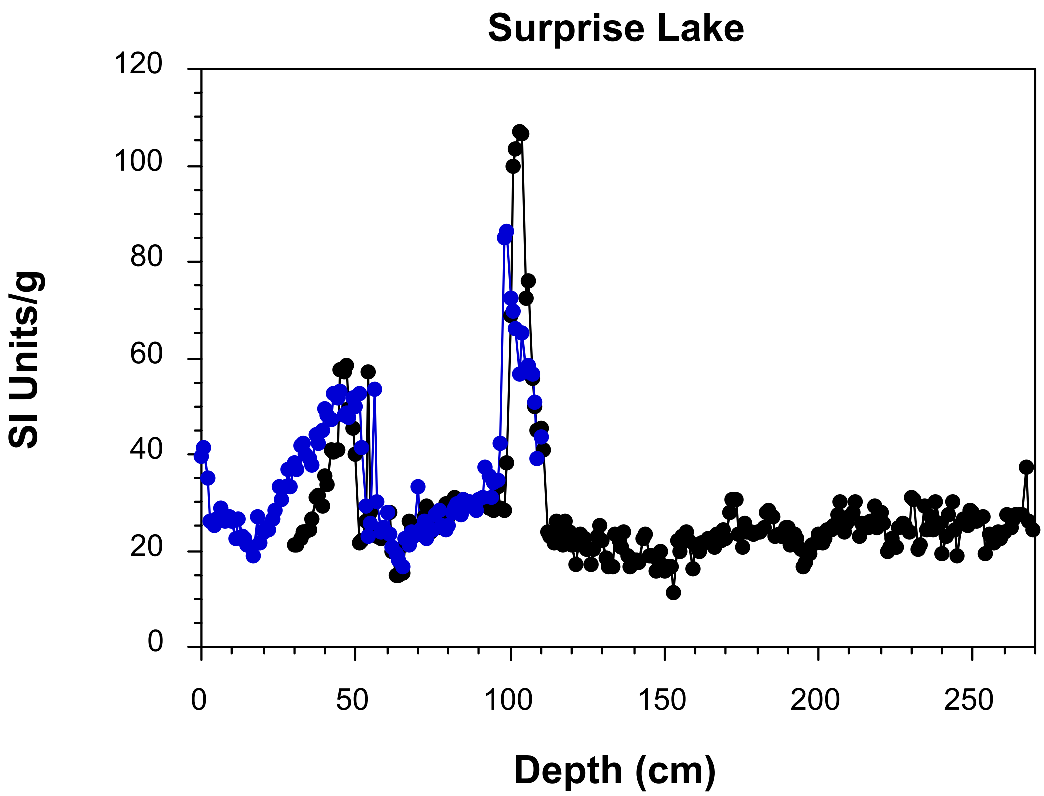

Figure 13. Magnetic susceptibility vs. depth for Surprise Lake cores HC-5 (black) and HC-6 (blue). The cores were taken at the same location in the lake, and combined to produce a composite record as HC-6 contains undisturbed surface sediments, and HC-5 a longer record. The depths in HC-5 were offset based on correlation at the upper tephra unit at ~50 cm.

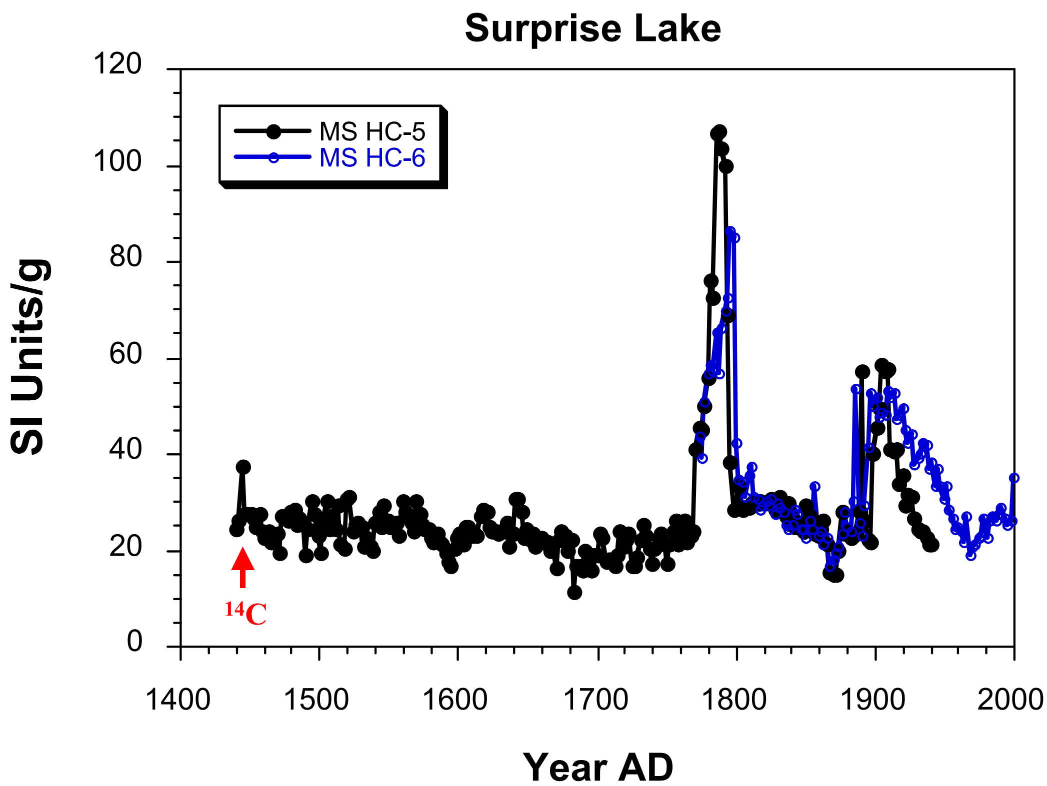

Figure 14. Magnetic susceptibility vs. estimated age for the HC-5/6 record. A simple age model was constructed based on the coring date and the calibrated basal radiocarbon date (~1450 AD). This model suggests that the upper tephra is likely the 1931 Aniakchak volcanic event.

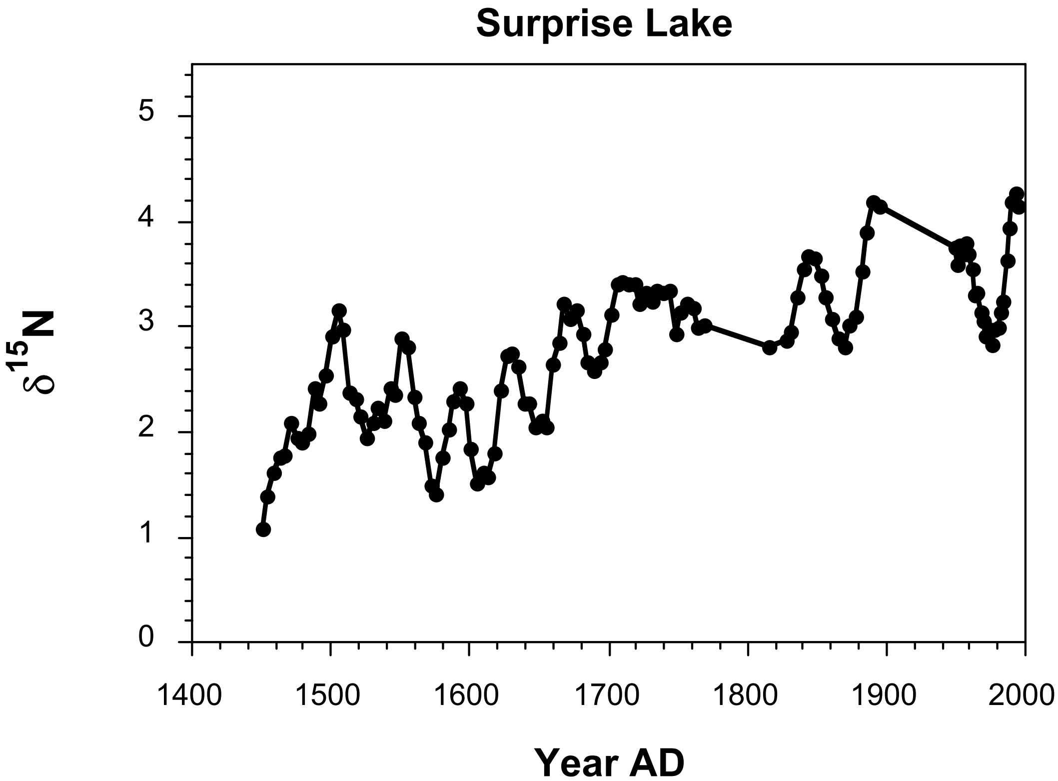

Figure 15. Stable nitrogen isotope data ($\delta^{15}N$) vs. age for Surprise Lake composite core HC-5/6. The calibrated age scale was determined as described in Figure 14.

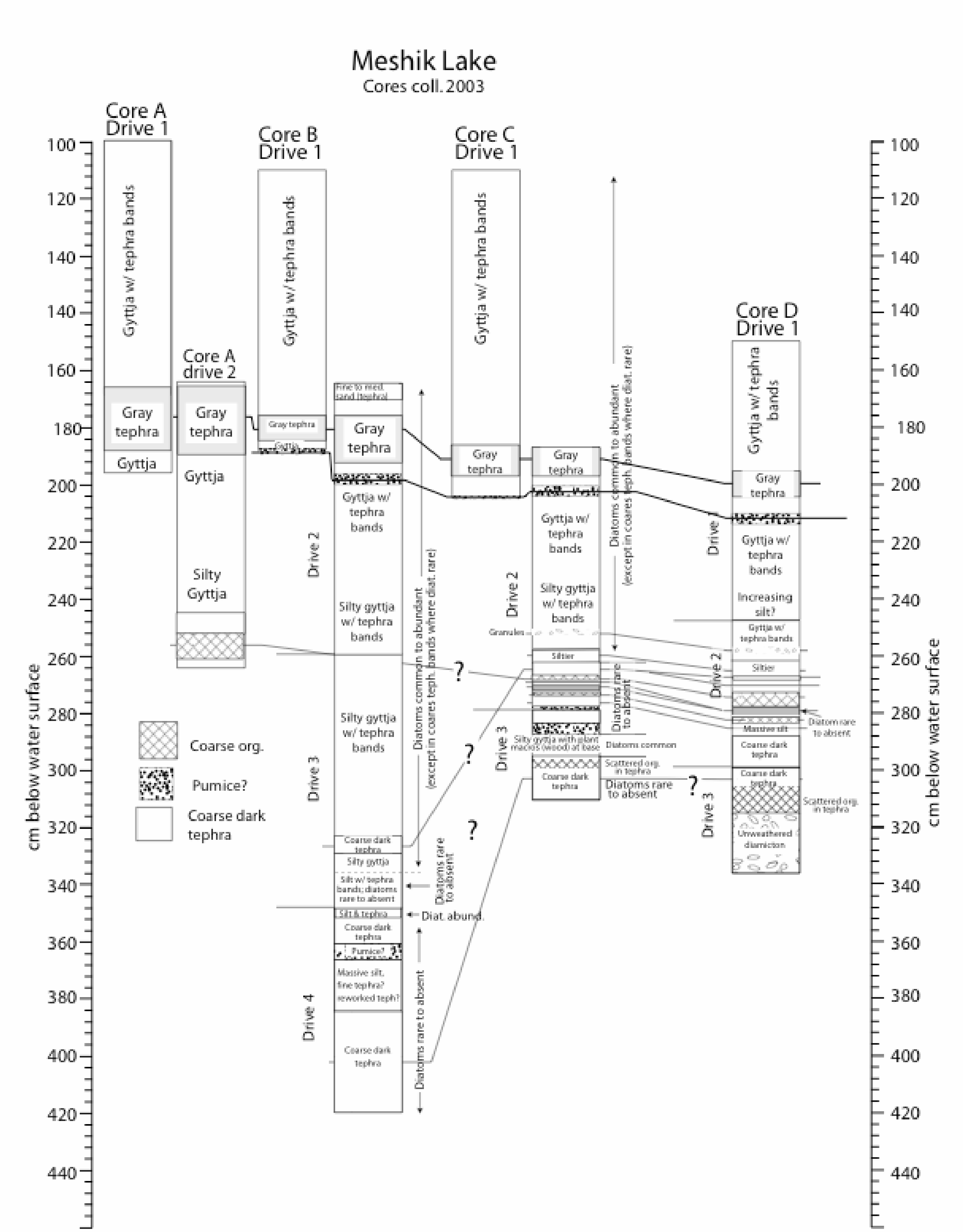

Figure 16. Core stratigraphy for the Meshik Lake cores, with suggested correlations

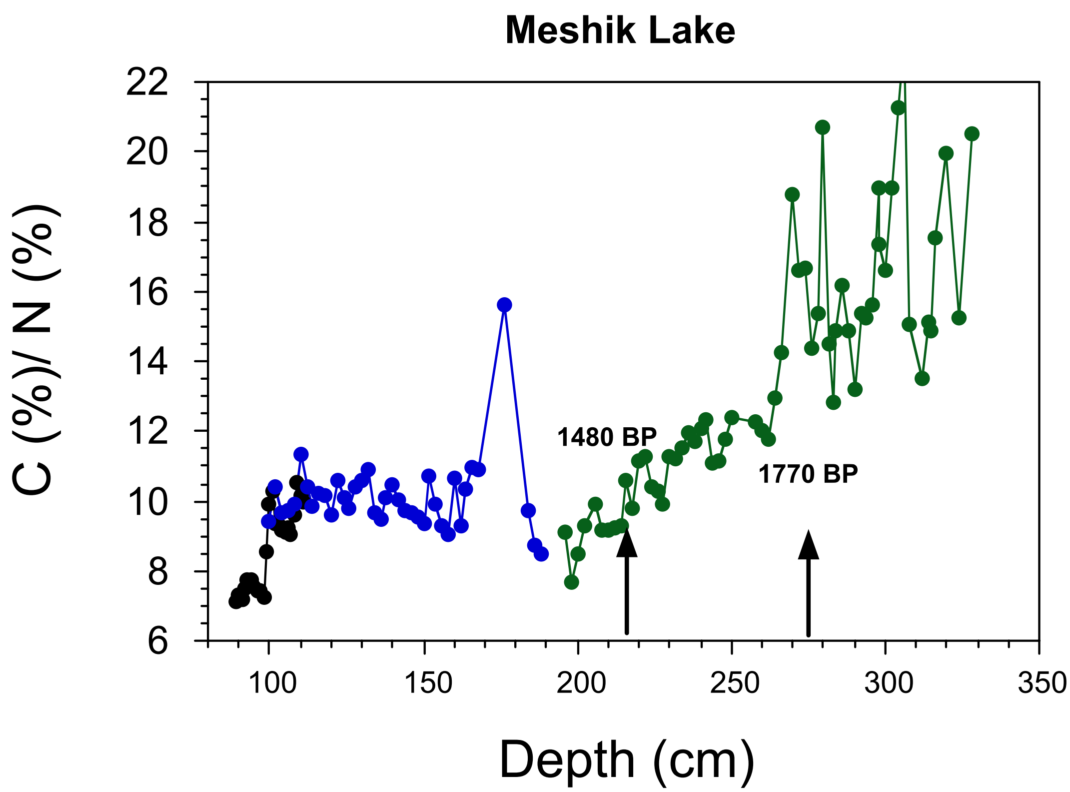

Figure 17. The C/N ratio (weight percent) vs depth for Meshik Lake composite core C/D. The higher C/N values below about 260 cm correspond with a unit that predates the establishment of the lake, that is dominated by terrestrial organic matter. Some relevant calibrated radiocarbon dates are shown, indicating the establishment of the lake at ca.1700 yr BP.

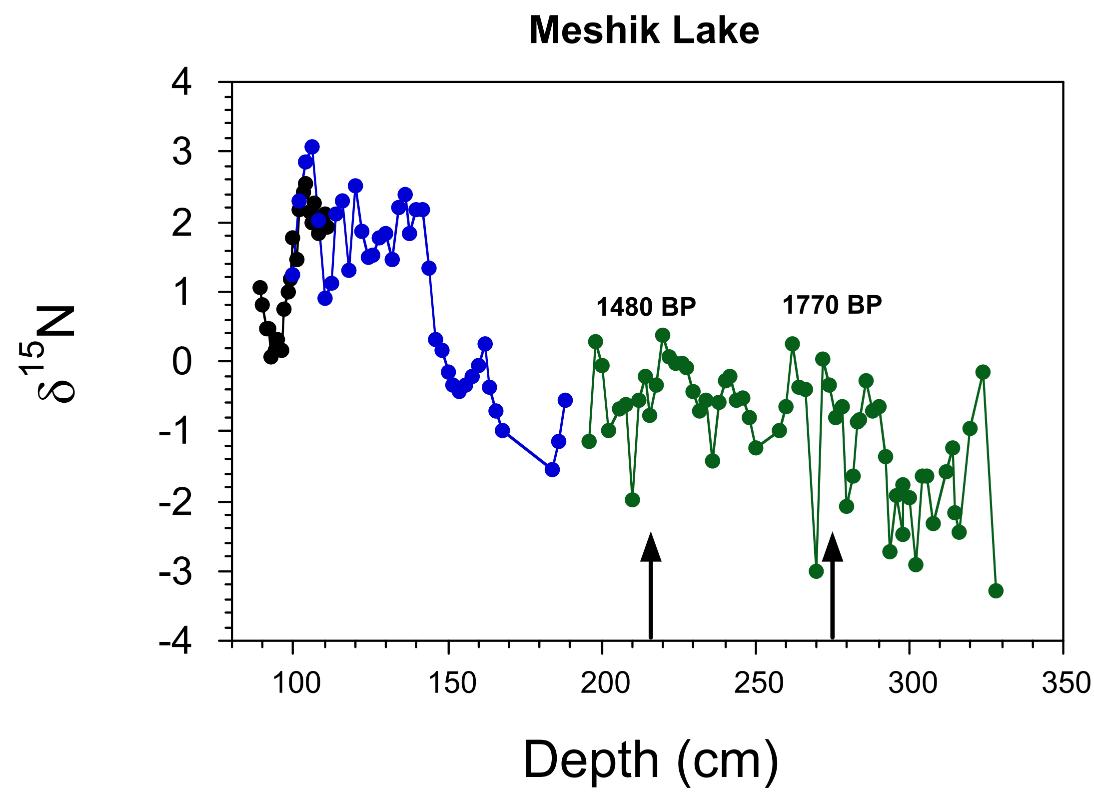

Figure 18. Stable nitrogen isotope ($\delta^{15}N$) profile vs. depth for Meshik Lake composite core C/D. Note the relatively higher values in the lacustrine unit (above 260 cm).

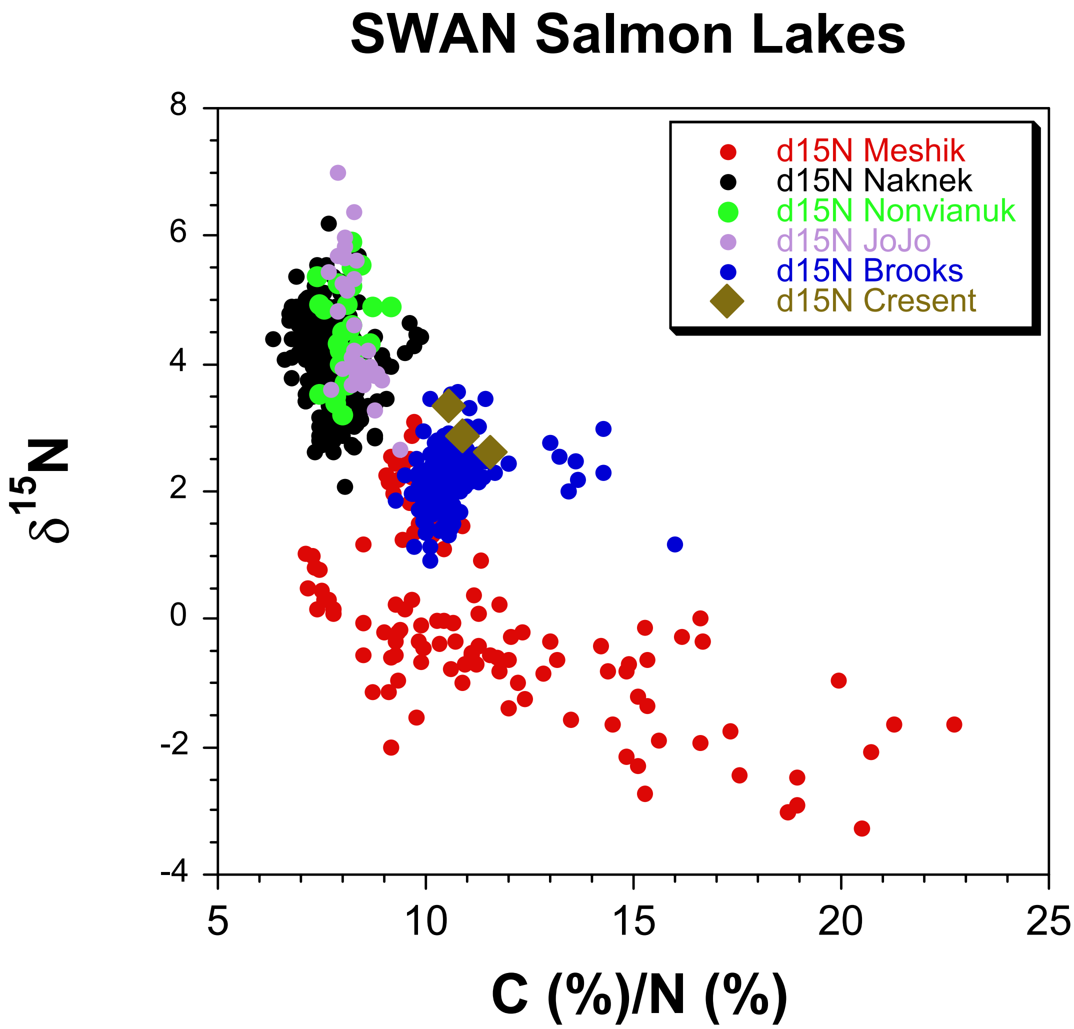

Figure 19. Scatter plot of $\delta^{15}N$ vs. C/N weight ratio for sediments from selected lakes analyzed as part of this project. Variability along the X-axis can be related to changes in organic matter source, with aquatic sources typically having values of <10, and terrestrial organic matter typically having higher values. Variability along the Y-axis ($\delta^{15}N$) may be due to variability in the relative contributions of salmon-derived nutrients, with higher $\delta^{15}N$ values representing higher relative salmon runs. As discussed in the text, baseline $\delta^{15}N$ values can vary from system to system based on a range of watershed and limnologic factors.